Supplement to the Key Bridge Proposals to Administer a Environmental Sensing Capability

Laboratory Testing of ESC Sensor Devices

Preliminary Test Report Summary

GN Docket No. 15-319

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Opening letter

Key Bridge Wireless LLC (fmr Key Bridge Global LLC, dba “Key Bridge”, “Key Bridge Wireless”) is pleased to submit this supplement to our proposal to administer a Environmental Sensing capability (ESC) in the 3.5 GHz frequency band.

The full report is over 200 pages and may be downloaded from our web site.[1] This document provides a summary of the attached preliminary test report, which provides detailed results for preliminary, that is “pre-certification”, evaluations and observations identified in NTIA technical documents TM-18-526, TM-18-527 and TM-18-534.[2, 3, 4]

As detailed in our original proposal, Key Bridge intends to upgrade the spectrum sensors used in our ESC from time to time. We are committed to test and verify operational conformance of each component prior to deployment.[5] To this end we have developed a completely automated ESC sensor testing capability that builds upon signal generation scripts and guidance helpfully provided to all prospective ESC administrators by the NTIA’s Institute for Telecommunication Sciences (ITS).

We are presently evaluating three different sensor devices to support different configurations and physical requirements that our ESC will encounter, which range from remote locations with extreme cold, hot, dry and wet outdoor conditions to climate controlled, on-net telecommunications facilities. This report provides test details for the first and most common sensor apparatus that we intend to use: the Keysight N6471A radio frequency sensor for signal monitoring networks. This product should be well known to the Commission and NTIA / ITS as it is in common use by the Commission and ITS.

We thank the Commission for its continued leadership and the opportunities it has created for small businesses like Key Bridge to innovate and succeed in spectrum sharing and wireless communications. Key Bridge is happy to provide any additional information the Commission may request to better evaluate this report.

/s/

Jesse Caulfield, CEO
Key Bridge Wireless LLC

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1 Download the full *ESC preliminary test report* from https://s3.amazonaws.com/keybridge-cdn/export/public/report/esc/2018-10-05+ESC+preliminary+test+report.pdf (31.5 MByte)

2 See NTIA, *Technical Memorandum 18-526, Distinction Between Radar Declaration and Pulse Burst Detection in 3.5 GHz Spectrum Sharing Systems*, October 2017, https://www.its.bldrdoc.gov/publications/3182.aspx

3 See NTIA, *Technical Memo TM-18-527 Procedures for Laboratory Testing of Environmental Sensing Capability Sensor Devices*, November 2017, https://its.bldrdoc.gov/publications/3184.aspx

4 See NTIA, *Technical Memo TM-18-534 Further Procedures for Laboratory Testing of Environmental Sensing Capability Sensor Devices*, June 2018, https://www.its.bldrdoc.gov/publications/3207.aspx

5 See Key Bridge, *Proposal to Administer a Environmental Sensing Capability*, GN Docket No. 15-319 received 05/13/2016

Introduction

The accompanying preliminary test report contains detailed test results for the various examinations and observations outlined in the NTIA technical memos **TM-18-527** and **TM-18-534** to test an ESC *sensor* apparatus to be used in an Environmental Sensing Capability (ESC) for the 3.5 GHz (3,500 to 3,700 MHz) radio frequency band in accordance with Part 96 Rules.

Evaluation of the Sensing Device

The purpose of the NTIA test suite is to evaluate the capability and performance of the SENSOR, not the ESC system as a whole. Certain ESC / CBRS specific safeguards and policy configuration are therefore not included and implemented, such as “safe” failure, strict band pass filtering, added channel blocking strategy for improved interference protection, etc. When incorporated into an ESC distributed sensor network, the sensor devices will operate with included CBRS policy configurations. An end-to-end ESC system test will be provided separately.

Examinations versus Observations

Two types of tests are described in the NTIA / ITS test documents: *examinations* and *observations*.

- **Examinations** are pass/fail performance-based tests to establish and confirm that a candidate apparatus can or cannot implement the required signal detections.
- **Observations** are non pass/fail qualitative evaluations of the apparatus to understand its performance in various, potentially atypical conditions. Observations are not considered for certification.

Two examination scenarios are described:

1. **Clean:** a “raw” radar signal at or above -89 dBm/MHz with no added noise
2. **With noise**: with Gaussian noise added at up to -109 dBm/MHz RMS average power

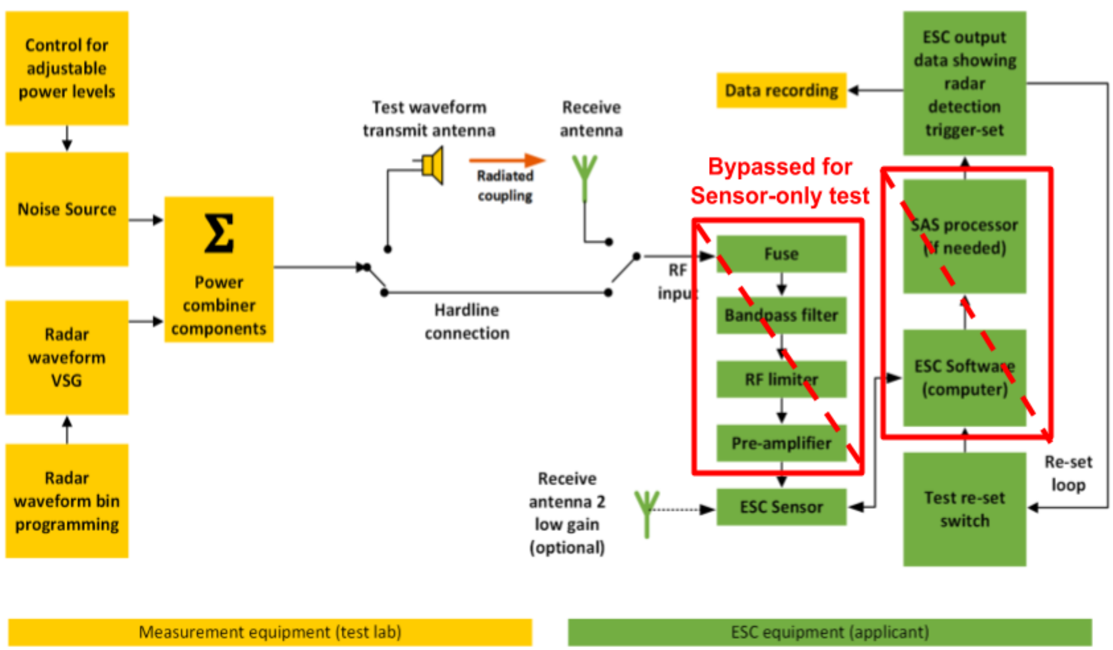
The three observation scenarios are:

1. **High power**: Bin 1 at -5.4 dBm/MHz, Bins 2-5 at +10.6 dBm/MHz
2. **Excess noise**: with Gaussian Noise added at -89 dBm/MHz RMS average or greater and with peak noise at -79 dBm/MHz or greater
3. **Out-of-band** (OoB): With an OoB signal injection operating below the sharing band edge i.e. below 3500 MHz and at +10.6 dBm/MHz power level.

Hardware Setup

This test suite evaluates the sensing device performance. It does not evaluate an end-to-end ESC solution. Therefore, while the full ESC solution employs many RF front-end elements as shown in the diagram below, the test results shown in this report are without any external RF front-end components. Specifically, no external bandpass filter, RF power limiter, or pre-amplifier were used.

Figure: Schematic block diagram for ESC performance testing



Adapted from NTIA TM-18-527

Input Parameters

The incumbent radar signal parameters were randomly sampled with uniform distribution from the parameter space defined in the table below from NTIA TM-18-527. Since only a randomly sampled subset of parameter space was tested, all the boundary / edge cases were also tested.

Table 1. Radar signal parameter bounds for 3.5 GHz ESC compliance testing.

Pulse Modulation	Pulse Width (µs)	Chirp Width (MHz)	PRR (pulses per second)	Pulses per Burst (Min to Max)	Comments
P0N #1	0.5 to 2.5 Δ = 0.1	N/A	900-1100 Δ = 10.0	15 to 40 Min Δ = 5	Similar to currently deployed Radar 1
P0N #2	13-52 Δ = 13	N/A	300-3000 Δ = 10.0	5 to 20 Δ = 5	Simulates possible phase-coded waveforms that could be used in future radar modulations
Q3N #1	3-5 Δ = 1.0	50-100 Δ = 10	300-3000 Δ = 30	8 to 24 Δ = 2	Simulates possible future multi-function Q3N-type radar • Short τ • Wide Bc
Q3N #2	10-30 Δ = 1.0	1-10 Δ = 1	300-3000 Δ = 50	2 to 8 Δ = 2	Simulates possible future multi-function Q3N-type radar • Intermediate τ • Intermediate Bc
Q3N #3	50-100 Δ = 5.0	50-100 Δ = 10	300-3000 Δ = 100	8 to 24 Δ = 2	Simulates possible future multi-function Q3N-type radar • Wide τ • Wide Bc

Source: NTIA TM-18-527

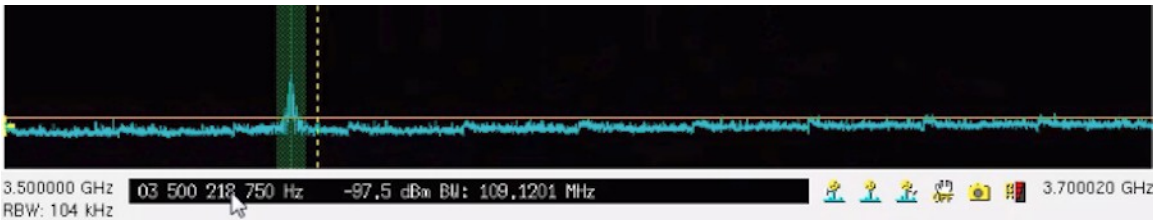
Additionally, the input amplitudes and frequencies were varied as follows:

Parameter	Range	Step size
Input amplitude	about -45 to -89 dBm/MHz	typically 10 dBm/MHz
Input frequency	between 3550 - 3650 MHz	1 or 2 MHz

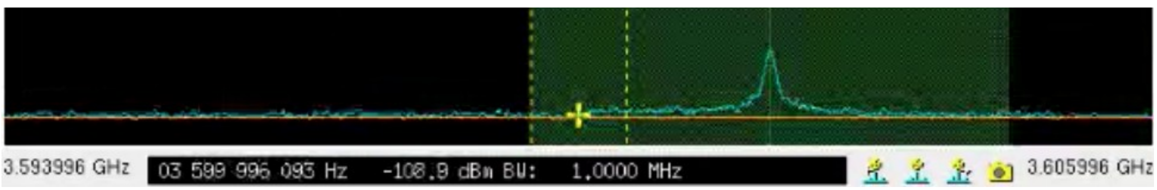
Sample Signals

Representative sample spectographs (averaged over time) showing the five classes of input radar signals tested.

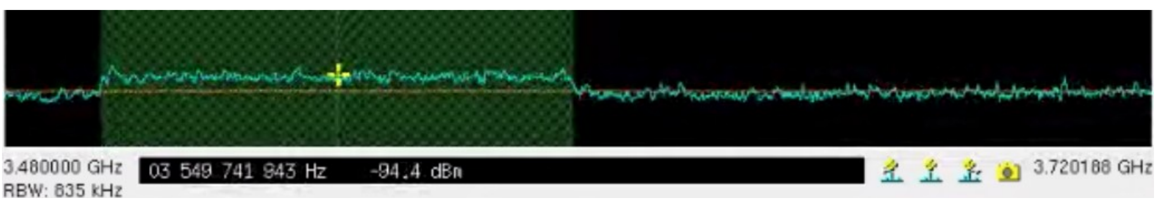
Bin 1 / P0N #1



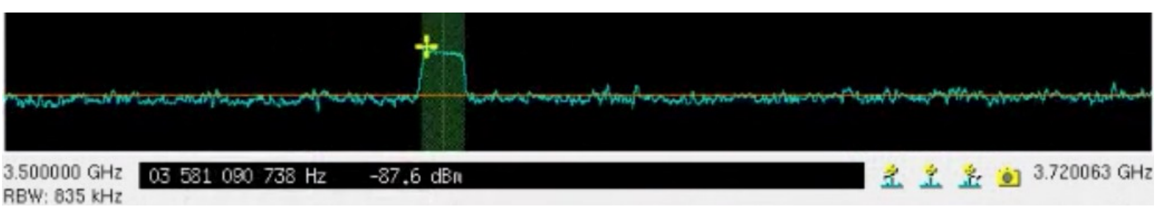
Bin 2 / P0N #2



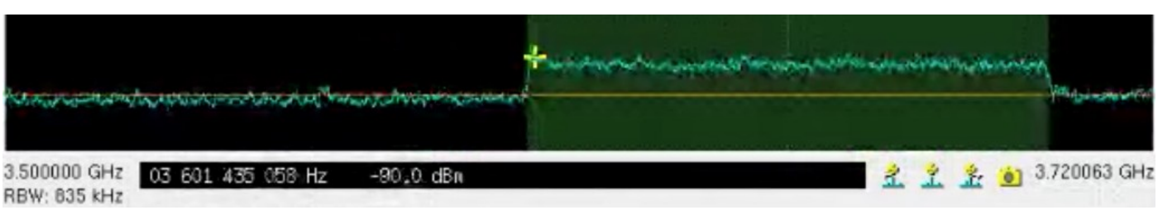
Bin 3 / Q3N #1



Bin 4 / Q3N #2



Bin 5 / Q3N #3



Test criteria and organization

The Key Bridge ESC test report includes results organized into three categories that are derived from and extend the definitions presented in NTIA TM-18-526:

- *detection* of RF energy,
- *declaration* of presence of incumbent radar signals,
- *identification* of CBRS channels based on detected incumbent signal channel occupancy

Detection, Declaration, and Identification of Incumbent Occupied Channels

Under the examination conditions, detection and declaration must occur with at least 99% probability and at most 1% standard error. Detection and declaration must also occur within 5 and 60 seconds, respectively, counting from signal transmission. In addition to detection and declaration, a sensor must correctly identify the incumbent operating frequency or frequencies.

Probability of Detection required	Probability of Declaration required
99% with a 1% Standard Error within 5 seconds	99% with a 1% Standard Error within 60 seconds

A key objective of the ESC system is to protect incumbent operations from harmful interference. Therefore it is critically important that the sensor correctly identify the CBRS channel(s) used by an incumbent transmitter. There are three possible channel identification conditions:

- *under protection*: where a subset of incumbent occupied channels are identified,
- *correct protection*: where the exact set of incumbent occupied channels are identified, and
- *over protection*: where channels not occupied by the incumbent are incorrectly detected

The “Correct” and “Over” conditions adequately protect an incumbent system and are acceptable. “Under” protection is considered an error condition.

Results summary

The overall results of detection of RF energy, declaration of presence of incumbent radar signal, and identification of incumbent occupied channels are close to 99% for all categories except for the out-of-band (OoB) emissions condition. For the pass/fail examination conditions (clean and with noise), we find 100% detection and 100% declaration of incumbent radar signal presence and close to 99% successful channel identification for interference protection. We are developing and testing improvements for detection of low power signals in the presence of high-power out of band emissions and will publish those results when available. There is also more work to be done to improve channel identification accuracy; specifically reducing overprotection of the Bins 3,4 and 5 radar profiles.

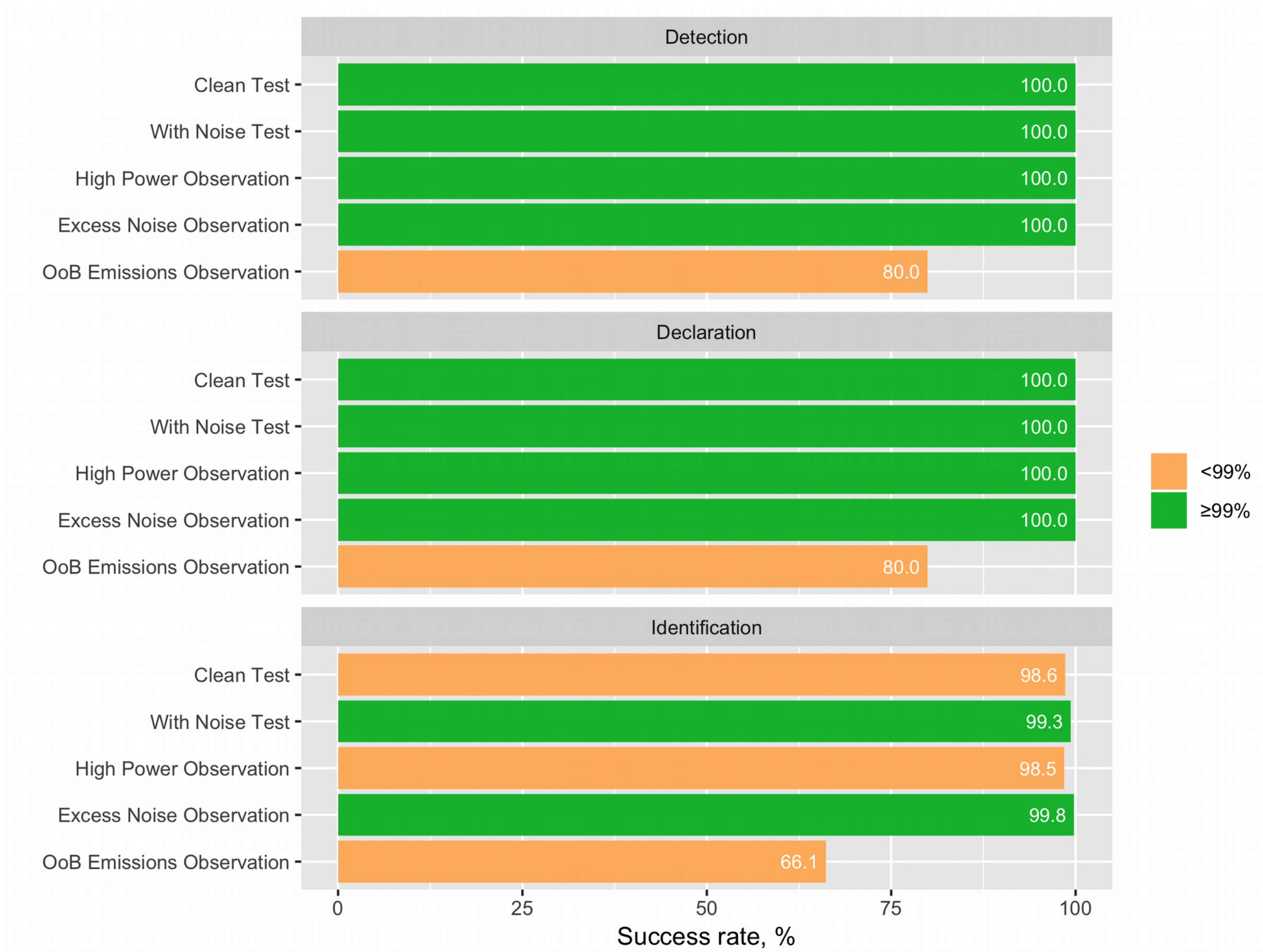


Illustration 1: Evaluation summary

The full ESC solution will include additional RF front-end hardware such as RF limiter, low noise pre-amplifier, bandpass filter, etc. which will improve these results significantly as well.

The more detailed channel occupancy identification results (i.e. under, correct, and over protection) shown below indicate that incumbent occupied channels are mostly being protected under all examinations and observations except the Out-of-band (OoB) emissions condition.

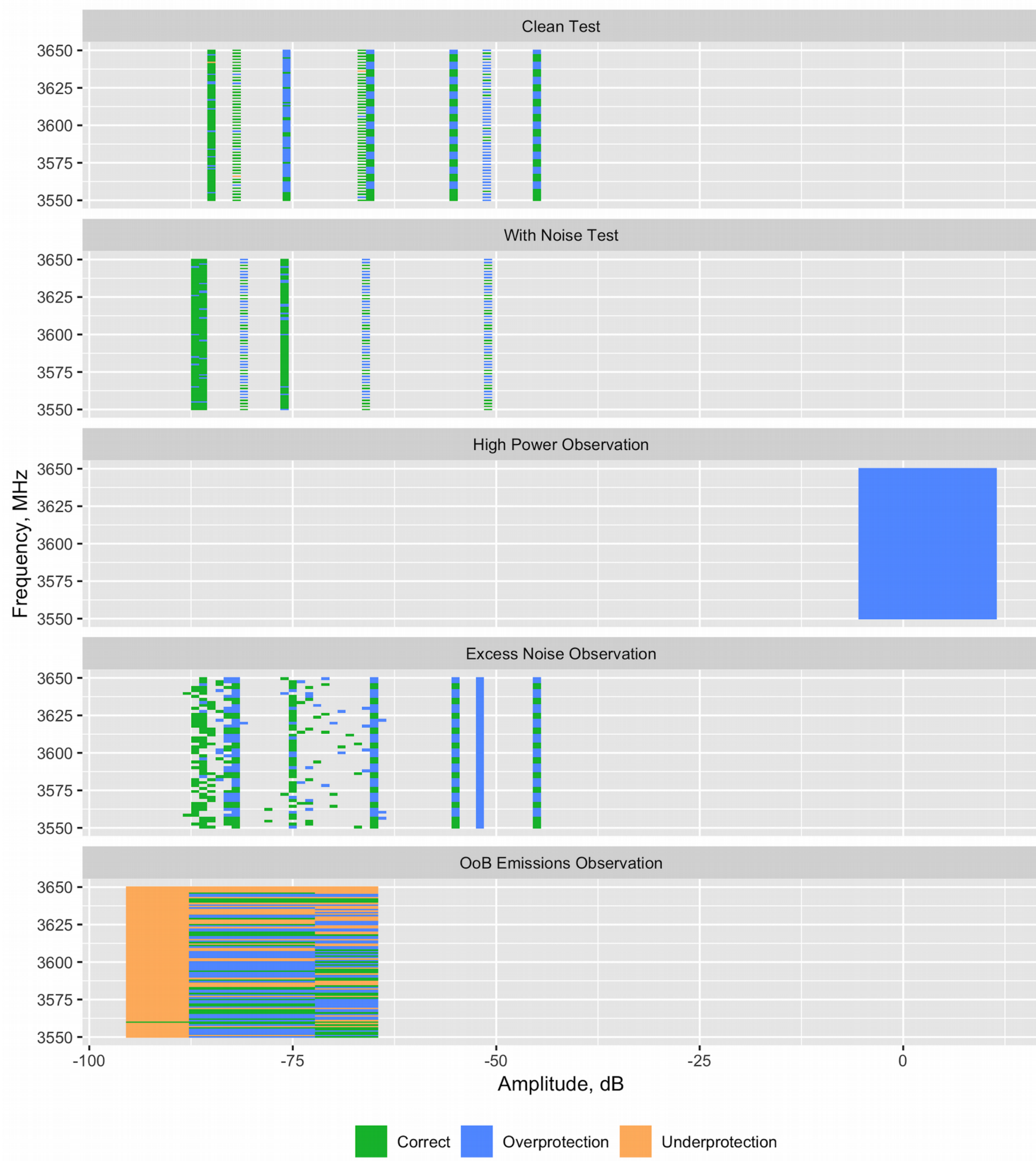


Illustration 2: Observation summary

Examination Tests

We present the performance results for detection, declaration, and channel identification under examination conditions (i.e. clean without added noise, and with added Gaussian noise) below.

Detection Results

Group	Tests	Detection (d)	%d	σd, %	Avg. t, s	Duration, h
Clean	4906	4906	100.0	0.0	2	10
With Noise	1068	1068	100.0	0.0	2	3
Overall	**5974**	**5974**	**100.0**	**0.0**	**2**	**12**

Declaration Results

Group	Tests	Declaration (D)	%D	σD	Avg. t, s	Duration, h
Clean	4906	4906	100.0	0.0	2	10
With Noise	1068	1068	100.0	0.0	4	3
Overall	**5974**	**5974**	**100.0**	**0.0**	**2**	**12**

Channel Identification Results

Group	Tests	Id (I)	%I	σI	%Correct	%Under	%Over
Clean	4906	4837	98.6	0.2	51.1	1.4	47.5
With Noise	1068	1061	99.3	0.2	64.3	0.7	35.0
Overall	**5974**	**5898**	**98.7**	**0.1**	**53.5**	**1.3**	**45.2**

In channel identification we confirm the sensor correctly detects and identifies the 10 MHz channel in which an incumbent signal is transmitted. For this test there are three possible outcomes:

- **Correct**: where the sensor exactly matches the incumbent channel or channels
- **Over**: where the sensor matches the incumbent channel or channels plus others
- **Under**: where the sensor fails to identify all incumbent occupied channels

Clean (without any added noise):

Without any noise added, the system detects and declares presence of all types and classes of incumbent radar signals at 100% (0% std. error) within average duration of 2 seconds. Additionally, the system either correctly identified or overprotected the incumbent occupied CBRS channels in 98.6% (0.2% std. error) of the test runs.

The under protection failure is strongly indicated for for Bins 3 and 5. These Bins 3 and 5 waveforms have relatively wide signal chirp widths and are difficult to isolate. An example is shown in the figure below where the the sensor is challenged to accurately identify the center frequency and span. In this case the trailing edges are missed. The figure shows a sample Bin 3 input signal and the green shading indicates detection by the sensor. In the figure, we can see that the green shading does not fully cover the radar waveform at the edges which leads to under protection. This is an area of active development to improve and fine tune the filters to detect the edges more precisely.

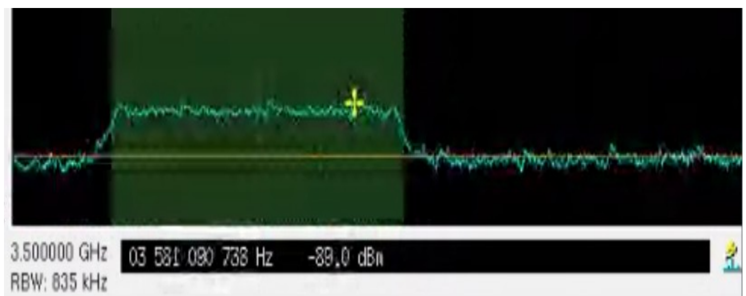


Illustration 3: Under protection at edges of a Bin 3 radar signal (figure shows average over time)

Radar signals in Bins 1 and 2 are frequently overprotected. While this is not an issue for incumbent channel protection, we are currently working to improving and fine tuning the filters to detect the edges more precisely. A sample of such filters is shown in the figure below.

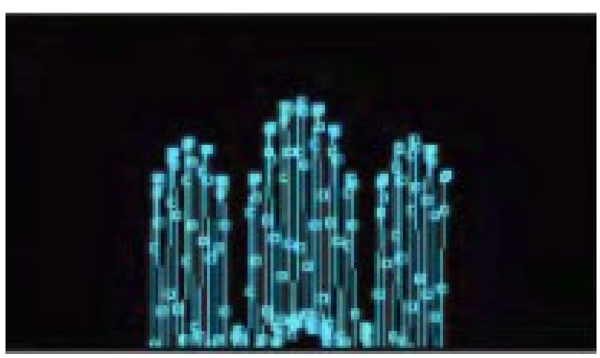


Illustration 4: Sample signal detection filter

With Gaussian noise:

With added noise at -109 dBm/MHz average RMS,the system detects and declares presence of all types and classes of incumbent radar signals at 100% (0% std. error) within average duration of 4 seconds.

Additionally, the system either correctly identifies or overprotects the incumbent occupied CBRS channels in 99.3% (0.2% std. error) of the test runs.

Similar to the clean (no added noise) condition before, the under protections occur mostly for Bins 3 and 5. Signals in these bins have relatively wide signal bandwidths so the sensor does not discern where the signal edges are exactly.

We are currently working to improving the filters to detect the edges more precisely.

Observation Tests

Detection Results

Group	Tests	Detection (d)	%d	σd, %	Avg. t, s	Duration, h
Excess Noise	1275	1275	100.0	0.0	2	3
High Power Tests	10494	10493	100.0	0.0	2	21
OoB Emissions Tests	3636	2907	80.0	0.7	2	8
Overall	**15405**	**14675**	**95.3**	**0.2**	**2**	**30**

Declaration Results

Group	Tests	Declaration (D)	%D	σD	Avg. t, s	Duration, h
Excess Noise	1275	1275	100.0	0.0	4	3
High Power Tests	10494	10493	100.0	0.0	3	21
OoB Emissions Tests	3636	2907	80.0	0.7	3	8
Overall	**15405**	**14675**	**95.3**	**0.2**	**3**	**30**

Channel Identification Results

Group	Tests	Identification (I)	%I	σI	%Correct	%Under	%Over
Excess Noise	1275	1272	99.8	0.1	55.7	0.2	44.1
High Power Tests	10494	10333	98.5	0.1	64.6	1.5	33.8
OoB Emissions Tests	3636	2404	66.1	0.8	34.6	33.9	31.5
Overall	**15405**	**14009**	**90.9**	**0.2**	**56.8**	**9.1**	**34.2**

High power signal:

With high power input signals, the system detects and declares presence of all types and classes of incumbent radar signals at 100% (0% std. error) within average duration of 3 seconds. Additionally, the system either correctly identifies or overprotects the incumbent occupied CBRS channels in 98.5% (0.1% std. error) of the test runs.

We expect the results for this test to improve with inclusion of the external RF limiter in the full ESC system as a RF limiter was not used for the results presented here. The current system attempts to detect and declare channels even in the presence of high power and saturation filtering was turned off for the test. In a live environment, when the sensor is saturated the affected channels will be marked as “occupied” or the sensor will declare itself unable / out of service.

Excess/High noise level:

With high noise levels signals, the system detects and declares presence of all types and classes of incumbent radar signals at 100% (0% std. error) within average duration of 4 seconds. Additionally, the system either correctly identifies or overprotects the incumbent occupied CBRS channels in 99.8% (0.1% std. error) of the test runs.

We expect inclusion of additional RF front-end filter elements including the low noise pre-amplifier, RF limiter, and band-pass filter, in the full ESC solution to improve the performance under this test condition.

Out-of-band (OoB) Emissions:

Out-of-band interfering emissions tests were performed using a 10 MHz wide OoB QPSK signal centered at 3.45 GHz.

With this out-of-band interference, the system detects and declares presence of all types and classes of incumbent radar signals at 80% (0.7% std. error) within average duration of 4 seconds. Additionally, the system either correctly identifies or overprotects the incumbent occupied CBRS channels in 66.1% (0.8% std. error) of the test runs.

The relatively poor performance for out-of-band emissions tests can be attributed to the system having difficulty in discerning actual in-band radar signal in the presence of a similarly modulated out of band signal. Additionally the current test setup tests the “raw” equipment and does not include any additional band pass filters. Therefore, the current sensing algorithm is not “trained” to look for and suppress out of band signals. We expect the results to improve significantly with inclusion of external RF components, including the bandpass filter, and we are also actively improving the filters to identify in-band radar signals more precisely. This is the last test condition in our development train and hence is still under development.

Conclusion

This report provides test details for the first and most common sensor apparatus that we intend to use in our phase one ESC deployments, the Keysight N6471A Radio Frequency Sensor for Signal Monitoring Networks.

The NTIA / ITS test suite evaluates the capability and performance of a sensor apparatus and not the ESC system as a whole. The suite includes two categories of test: *examination* and *observation*. Examinations are pass/fail performance-based tests that determine whether the apparatus is technically capable to implement the required observations, while Observations are qualitative evaluations to of the apparatus' performance in various, potentially atypical conditions.

In this first evaluation of our ESC configuration based upon the Keysight N6471A radio frequency sensor we have established close to 99% detection and declaration of all incumbent radar signal typies, and correct identification of incumbent occupied channels for all categories except for the the out-of-band (OoB) emissions condition. For the pass/fail examination conditions (clean and with noise), we find 100% detection and 100% declaration of incumbent radar signal presence and close to 99% successful channel identification. The sensor had difficulty identifying low power signals in the presence of high-power out of band emissions.

It should be noted that the tests undertaken evaluate the radio sensing apparatus and not an end to end ESC solution. The full ESC solution will include additional RF front-end hardware such as RF limiter, low noise pre-amplifier, bandpass filter, etc. plus additional control and event analysis software. Together these ESC additions will significantly improve the overall system performance. We continue to develop and test further improvements on this and other sensors. We also look forward to end-to-end testing in a live field trial. We will publish additional testing results as they become available.

We thank the Commission for its continued leadership and we are happy to provide any additional information the Commission may request to better evaluate this report.

/s/

Jesse Caulfield, CEO

Key Bridge Wireless LLC